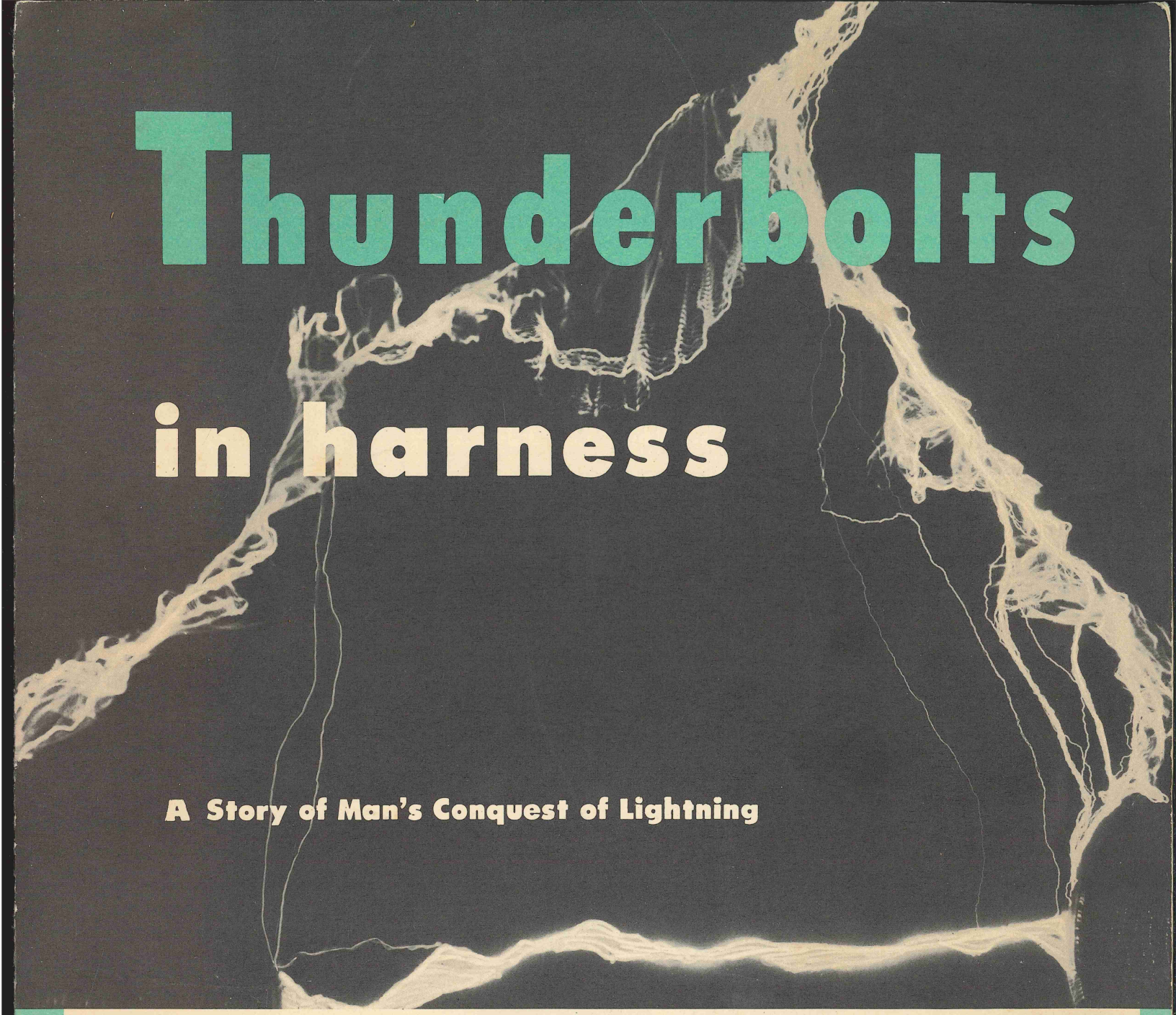

Thunderbolts in harness

A Story of Man's Conquest of Lightning

FOR century upon century men watched in awe and fear as stormy skies cast jagged streaks of lightning earthward with ominous crashing. Surely, it was the ire of the gods, they said. And they made sacrifices to appease these angry deities. The bold Teutons of northwestern Europe believed it was the god of war, who amused himself by hurling bolts of lightning into their forests.

The first faint inkling of the truth about lightning is recorded in American history books. It is the story of one of the founders of the United States, the statesman - philosopher - inventor Benjamin Franklin and his experiment with kite and key. Franklin discovered that lightning is electricity. He then invented the lightning rod to protect buildings from it

A Bolt Writes in Fire

We may say that Benjamin Franklin was the author of the prologue to *Thunderbolts in Harness*. The first chapter wasn't written until nearly two centuries later, when engineers began experiments to reproduce lightning in the laboratory.

It was a hot afternoon in August, 1920. The story told by the brief flash of electricity might have gone unnoticed if the bolt hadn't struck the summer camp of one of the few men who could and would read it—in the broken pieces of a mirror.

The man was a short, bearded, German-born genius, with a twisted, dwarfed body—Charles Proteus Steinmetz.

A Story in a Mirror

The lightning struck Steinmetz' small

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cottage, perched on a bank close to the Mohawk River, a few miles from his General Electric laboratory in Schenectady, New York. No one could tamper with the trail it left. Steinmetz went over the place like a detective hunting clues to a murder. He pieced the damaged mirror together, and thus began the first scientific study of lightning.

The day of electricity to do man's work had arrived, and power stations and power lines were fanning out in all directions in ever-increasing numbers. Lightning, the unconquered "weapon of the gods," was a very real menace. When it struck it wrought havoc to man's spiderweb of electric lines. Interrupted electrical service was a commonplace occurrence. The more man depended on electricity, the more serious became its interruption.

Steinmetz puffed a cigar and reasoned that the best solution to the problems created by lightning was to study lightning itself. Easily said, but not so easily done, since no one knew where or when lightning would strike.

But why not make lightning?

1922 Is Historic Date

There were scoffers, naturally, when the wizened, little wizard began building his first artificial-lightning generator in 1921. It was a queer contraption, with stacks of large glass plates, coated with metal foil, and connected here and there with wires. But it worked, and in 1922, the first sizeable man-made bolt of lightning using power equipment flashed across a gap, accompanied by a loud clap of artificial thunder. With a potential of 120,000 volts and 1,000,000 horsepower, it was only about one five-hundredth as powerful as natural lightning. But scientists and engineers could control it; they could study it. They knew when, where, and what it would strike.

The next year a larger and more powerful lightning generator was built; but Steinmetz never got the chance to use it. He died before it was completed.

In Pittsfield, Massachusetts, another General Electric scientist, Frank W. Peek, Jr., who had come from Schenectady in 1913, was testing high-voltage electric power equipment. The following year the first high-voltage laboratory was built under his direction, and soon after that time work began with high-voltage impulses, in connection with the design of lightning arresters.

Peek Takes Up Study

It is not surprising that in his quest for better and better power transformers and distribution equipment Peek took up the study of lightning where Steinmetz had left off. In 1928 he built a 3,600,000-volt lightning machine—a "big gun."

But lightning research was progressing rapidly and before many years the "big gun" was superseded. Peek went on to develop a 5,000,000-volt, and then a 10,000,000-volt lightning generator. The 10,000,000-volter's bolt jumped 30 feet.

These last two lightning machines followed the invention of a new type of impulse-generator circuit called the Marx circuit, after its inventor. It solved many of the lightning hunters' problems of expense and space by charging the generator's capacitors or storage reservoirs in parallel and discharging them in series. That means little to the average reader, but it was a boon to the lightning men. In effect, it put man-made lightning in a suitcase. It enabled the scientists to pack up their bolts and take them out into the countryside where they could fire them at real power lines. A 1,000,000-volt portable generator was constructed under the direction of Dr. Karl B.

Edison and Steinmetz, who pioneered lightning studies, examine an insulator hit by artificial bolts.

In the 1930's this portable, million-volt lightning generator, below, went "on location" near Ithaca, N. Y.

McEachron soon after the Marx circuit came into being.

A Bout with Lightning

Dr. McEachron was at that time engaged in high-voltage research on lightning arresters. He became the director of the high voltage laboratory after Peek was killed in an automobile accident in 1933. Dr. McEachron has the dubious distinction of having once come in contact with 33,000 volts of electricity and living to tell about it. (It sent him to the hospital for nine weeks.)

The knowledge which scientists had gained from studying artificial lightning in the laboratory led them back to the source of their work—natural lightning. The twentieth-century lightning-hunters had tools which Benjamin Franklin never dreamed of—high-speed cameras whose film traveled past the lens at a mile a minute, oscillographs for recording the waves of electricity in a lightning stroke, and other sensitive electrical instruments. But like Franklin, they needed lightning.

An old adage states that lightning never strikes the same place twice, which is about as true as the theory that cats have nine lives. The lightning men picked a spot for their research that is struck by lightning dozens of times each year. In the heart of New York City, it's the top of the Empire State Building. Lightning experiments have been conducted there since 1935.

A Vigil in the Clouds

Each summer, in the "thunderstorm season," a man, who has to be part electrical engineer, part photographer, and part night watchman, takes up his vigil watching for lightning bolts to strike the mooring mast atop New York's loftiest skyscraper. Most of his work consists of sitting around waiting for thunderstorms, but when one comes he has to go into action fast.

Special high-speed rotating cameras focused on the top of the Empire State building are located in another skyscraper eight blocks away. Oscillographs and recorders are atop the Empire State building. When a storm is building up sufficient intensity to produce a stroke, these devices are automatically turned on by an electrical corona device. When the building is struck, the oscillographs automatically measure the stroke's characteristics.

A phone call warns the lightning watcher that a storm is approaching. No matter what time of night, he grabs a cab and rushes to the camera location and waits. Many times nothing happens except at distances too far to obtain good records. Frequently, however, the watch is rewarded by obtaining good lightning photographs.

A Youngster's Theory

When a bolt does strike, though, the lightning watcher is busy taking pictures and speaking into a voice recorder, describing what he sees as it happens.

Similar photographic research is carried on during the summer months in Pittsfield, from an observatory located on the roof of one of the city's tallest factory buildings. There, too, lightning watchers make the mad dash to the camera when a thunderstorm approaches.

One scientist's five-year-old daughter was slightly confused by the procedure. Many times at night, when the best lightning pictures are taken, she would hear her father get up to answer the telephone, then dress quickly and hurry out. Soon it would rain and there would be thunder and lightning. Convinced that her father had something to do with the storm, the little girl begged her mother to "tell daddy to turn it off."

Like a Pilot House

The setup and operation at the Pittsfield Observatory is somewhat different from that of the watching post in New York. From the Pittsfield observatory one can view the surrounding countryside for several miles in all directions. The lookout itself resembles the pilot house of an old-time Mississippi River boat. It is round and constructed almost entirely of glass and steel. The observer stands on an upper platform, where he views the heavens through a periscope which can be turned to cover the entire sky. Below him is a multiple-lens camera, set so that it will photograph all points on the horizon.

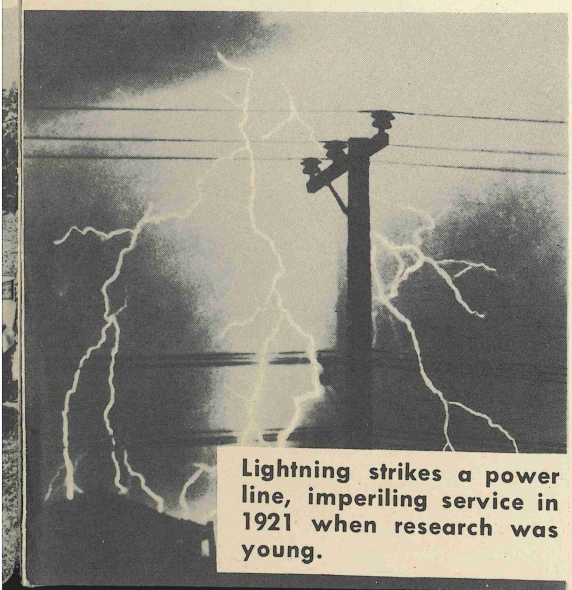
Though lightning research was rewarding John Q. Public with better and more dependable electric power all the time, he knew little about it until the New York World's Fair of 1939 and 1940. Literally millions of visitors to the man-made lightning "show" were thrilled or frightened as the 10,000,000-volt charge leaped the 30-foot gap between two generators, and artificial thunder crashed against the walls of the room and echoed back. The reactions of the audience ranged from nervous, self-imposed calm to downright uneasiness. The appearance of the darkened room with red signal lights glowing, the tall stacks of black and chromium, the shiny sphere-capped rods, the smell of ozone from previous "shows," and the ominous 15-second hum as the electric charge built up heightened the spell of tension. This spell was climaxed by the bolt of lightning and its thunderous crash. One of the demonstrations at the Fair was striking a hard maple post, which was blown violently apart by the lightning.

Buried for Posterity

(A film showing the 10,000,000-volt artificial lightning bolt has been buried in Oglethorpe University's "crypt of knowledge," to be opened and examined 6000 years from now.)

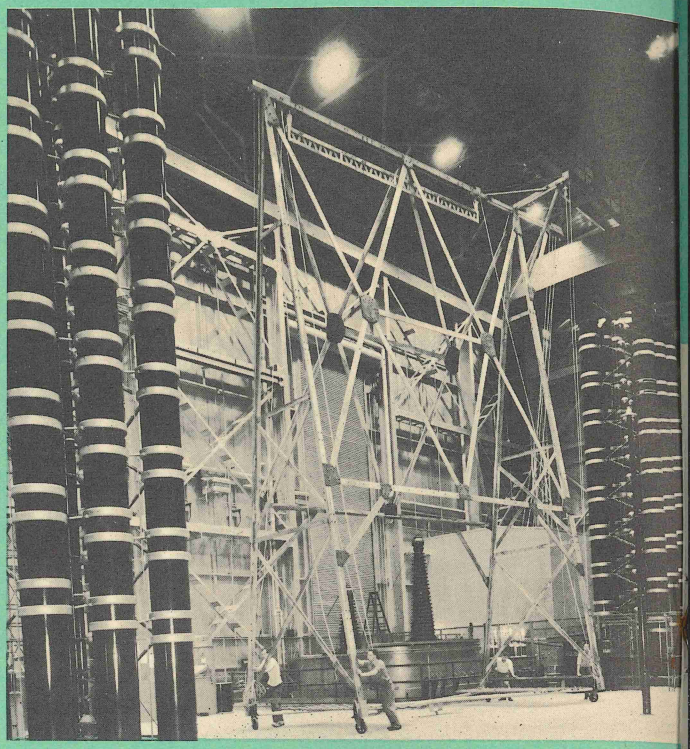
Dr. McEachron was appointed to the position of assistant works engineer in 1945, and two years later was made assistant manager of engineering for General Electric's Transformer and Allied Product Divisions. In 1945 Julius H. Hagenguth, his assistant for many years, became the new director of the high-voltage laboratory.

(Continued on page five)

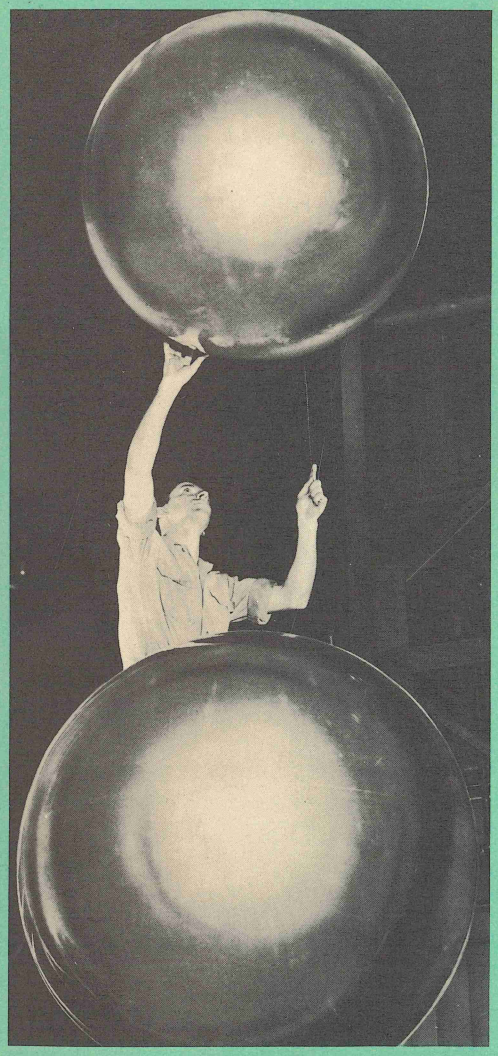


Lightning strikes a power line, imperiling service in 1921 when research was young.

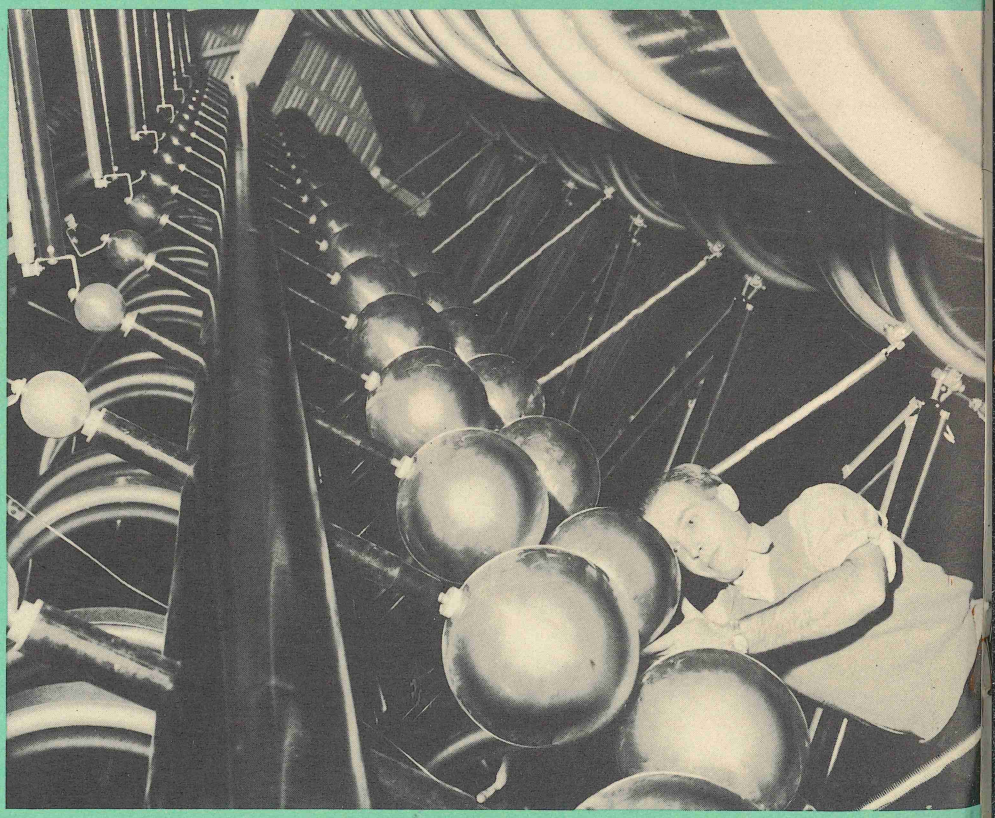
Leaders in present-day lightning research are General Electric's Karl McEachron and Julius Hagenguth.



Within the new High Voltage Laboratory at Pittsfield—moving the "A" frame, supporting the external circuit of a 5,100,000-volt impulse generator, into position.



By charging these spheres with high voltage electricity until a spark jumps between them, engineers can determine voltage magnitude.



Workman adjusts copper sphere on one of the two generators. Voltage increases as it travels up between banded capacitors until it reaches its peak. Then the generators discharge, and lightning flashes.

(*Continued from page three*)

TWENTY-FIVE years had passed since a bolt of lightning shattered a mirror in the Mohawk River camp of the late Charles Proteus Steinmetz and aroused his curiosity. Research on natural lightning had grown like a snowball rolling downhill. As Julius Hagenguth assumed directorship of the high-voltage laboratory at General Electric's Pittsfield plant, he had knowledge and equipment which had been gained and built up by a quarter century of hard work. Steinmetz had built a 120,000-volt lightning generator; Peek also was doing research, followed by McEachron. They contributed a 3,600,000-volt generator, a five-million-volt generator, increasingly better defense for power equipment, observations atop the Empire State building, and then a ten-million-volt lightning bolt that was in the limelight at the New York World's Fair, also much that was new concerning lightning as a phenomenon, providing data which hitherto had been lacking.

In June 1949 press, radio, and newsreel representatives sat in the gallery as "the world's largest man-made lightning center" opened with the flash and crash of a 15,000,000-volt bolt of lightning—a bolt which jumped a gap of 50 feet.

This bolt jumped at the *premiere* of General Electric's new High-Voltage Engineering Laboratory at Pittsfield, which was constructed under Hagenguth's direction.

Bolts in Cages

High-Voltage Hall, one of the main parts of the new laboratory, could be thought of as a gigantic circus lion tamer's cage, except that deadly lightning bolts instead of lions perform at their master's bidding. Also, the spectacle is more thrilling. The roar of the King of Beasts is tame compared to the ear-splitting crack of man-made thunder.

As a visitor enters through the gallery of High-Voltage Hall, he finds himself in a huge, windowless room 165 feet long, 95 feet wide, and 85 feet high. Two majestic 5,100,000-volt impulse generators dominate the scene. Each is made up of six 44-foot-tall stacks, jet black with shiny chromium rings around them every few feet. Nearby are transformers, controls, an oil tank for testing, and other weird apparatus used in experiments with powerful surges of electricity.

A 15,000,000-volt stroke of artificial lightning is about to be created. The lights in the room are turned off. Over a loudspeaker, a man in the gallery explains what will happen. Down below a crew of engineers moves around making sure all is in readiness. Then they move into a protective wire cage.

All Is in Readiness

"Are you ready down there?" the loudspeaker man asks.

"All set," comes back the answer.

There's a hum, and around the stacks there's an eerie bluish glow. Seemingly several minutes have passed, yet in reality it has only been a few seconds. The hum and the glow continue to hypnotize the spectators. With a little stretch of imagination you'd swear that Pittsfield had long since been left behind and that this was the laboratory of a mad scientist from Mars.

At last there's a loud warning buzzer. Some of the spectators cover their ears. Then . . . . . .

BANG. Simultaneously, a blazing streak of lightning jumps the 50-foot gap accompanied by a tremendous crack of thunder which sounds like a whole battery of big naval guns. It echoes

Lightning strikes a golfer—harmless to this metal model, disastrous to a person.

and re-echoes and rumbles from the steel and concrete walls.

After Image for Study

The brilliance of the 15,000,000-volt flash makes you blink, and you notice that the lightning streak has been reproduced on the retina of your eyes and can be seen for several seconds afterward if your eyes remained closed. So true is this picture that scientists frequently use this method to study the path of a lightning bolt which crossed the gap in 40-millionths of a second.

There are other fascinating and awe-inspiring things to be seen in High-Voltage Hall. The lightning men send 5,000,000 volts of electricity through a copper wire, which changes from a metal into gas amid a shower of sparks. Then you watch as a clothier's dummy with a metal golf club on her shoulder is struck by lightning. A model house is struck. Electricity is made to jump a string of 30 insulators to show how a flashover may be caused when lightning strikes an electric power line. Another demonstration is designed to show the protection offered to electric circuits by proper lightning arresters. A power line supplying the lights in a model house is struck by a 5,000,000-volt bolt. The lights go out. It's then struck again after lightning arrester equipment has been added. The lights shine brightly. Another exhibit is the splinter of a log which has been blown apart by the powerful laboratory lightning discharge. The path of the lightning through the log may be seen where the wood was vaporized; that is, turned to gas.

Pinwheels and Safety

The most colorful demonstration in High-Voltage Hall reminds one of a Fourth of July celebration. The display consists of a million volts of short-circuited electric power directed among three revolving pinwheels. The electricity, which has been colored with chemical mixtures at the ends of the pinwheels, jumps back and forth between the pinwheels, in numerous fiery, lacy arcs which snap and crackle. One arc may have two or even three colors in it red, green, yellow. The heat of the electricity causes the arcs to rise slowly as much as 20 feet above the pinwheels. The display lasts for several minutes.

It's rather ironical that man's biggest lightning center should be the safest place in the world during an electric storm, but that's a fact, according to Hagenguth. This is true because the metal walls, ceiling and the building's foundation are all connected electrically. Another system grounds all the test equipment. Personnel in High-Voltage Hall are protected by wire fences whose gates must be closed or all the test circuits remain broken.

One of the generators, weighing 25 tons, is mounted on a low flatcar which can be moved out-of-doors where experiments may be conducted on transmission lines and equipment too large to be taken into High-Voltage Hall.

A $2,000,000 Center

There are three other sections to this $2,000,000 lightning laboratory. In an adjoining building are seven high-voltage test areas. In one, experiments with powerful currents are conducted. In others, other electrical phenomena are studied. Less space is required for this equipment than is needed in High-Voltage Hall. Also in the same building is a controlled-temperature room, where tests are made under varied temperature and humidity conditions. Then there is an area of offices, a lecture room, five photographic darkrooms, chemical and physical laboratories, mechanical and electrical workshops, and other special test rooms.

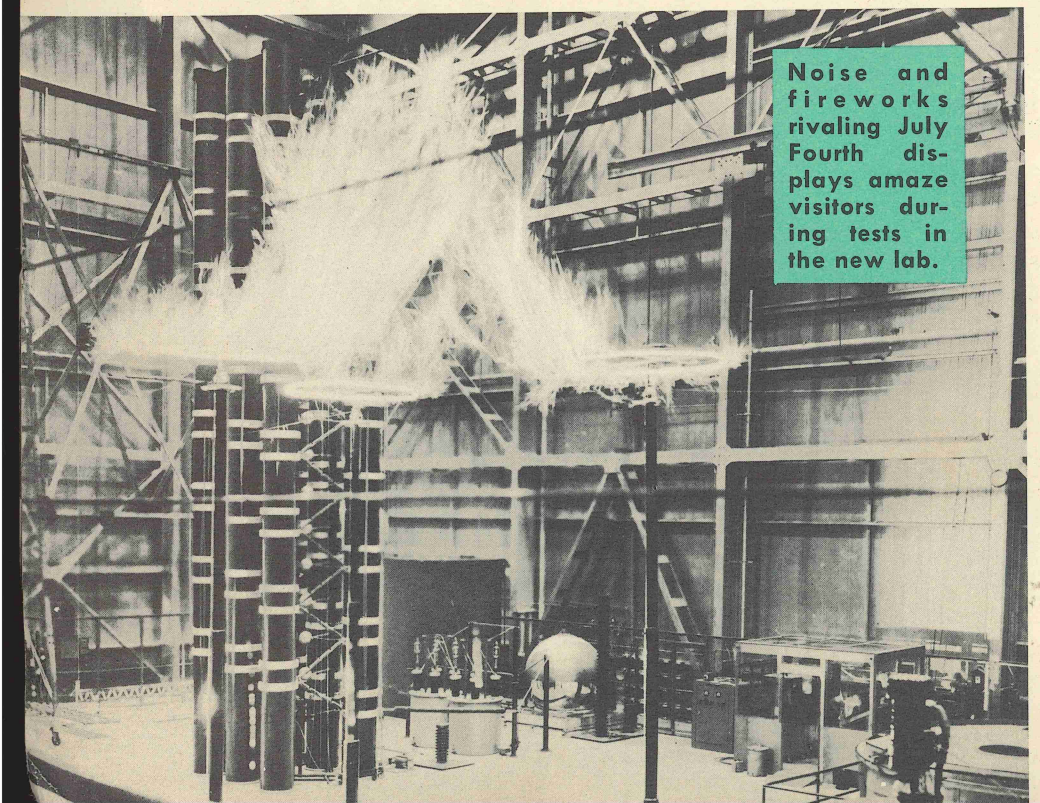
Though the lightning "shows" are probably most impressive to the visitor, the primary purpose of the High-Voltage Engineering Laboratory is not entertainment. Far from it. All the expensive equipment and highly trained personnel are there for one basic reason: to develop better and lower-cost high-voltage electric power equipment. Though lightning is the most colorful, it's only a part of the research in high-voltage electricity.

Menacing Thunderstorms

Today we are helpless without electricity, but it wasn't too many years ago that electric utilities would shut down their generating stations and disconnect their equipment, and farmers would pull their power switches when thunderstorms came near. The sudden surges of electricity wrought havoc with power lines or stations when it struck transmitting wires. Farmers' barns could be set afire by lightning entering through the wires.

It was a situation which could not be tolerated by the makers of electrical apparatus. That's why men like Steinmetz and Peek tackled high-voltage problems.

When lightning strikes an electric power line, there are two ways in which it usually causes damage if proper protecting devices have not been installed. They are (1) by flashing-over



Noise and fireworks rivaling July Fourth displays amaze visitors during tests in the new lab.

an insulator to the ground, often via a power pole; and (2) by continuing along the line to a power station where the surge of electricity may cause serious damage to equipment. In the former case the lightning also leads the power current to the ground, causing a short circuit and interrupting service.

Lightning did not run rampant for long, however. The inventive genius of men had produced the power lines; it produced protection for them. Today interruptions of electric service due to lightning are few and far between. The lightning arresters, special circuit-breakers, and other safeguards nullify the powerful "weapon of the gods."

Protections for Power

Most of these protective devices either disconnect the power line from the power station automatically immediately after lightning strikes and prevents power flow to the ground, or offers the lightning a quick way to the ground before it can damage equipment. The new High-Voltage Engineering Laboratory offers a place of research for scientists and engineers who will continue to develop better electric power equipment.

Lightning, player of devilish and sometimes disastrous pranks, has long been a favorite of storytellers. The tales are numerous and odd; and new ones are added each year during the summer "thunderstorm" season.

There's the story of the lightning bolt that ignited a building, then jumped to a fire alarm box nearby, bringing firemen to fight the blaze. A boy sitting in a cart under a tree was unharmed when lightning removed three sides of the cart. The entire side of a house in White Plains, New York, was shorn off by a stroke of lightning. In Pennsylvania 22 cows were killed by a lightning bolt which struck the tree they were standing under. A farmer's well went dry after lightning struck nearby.

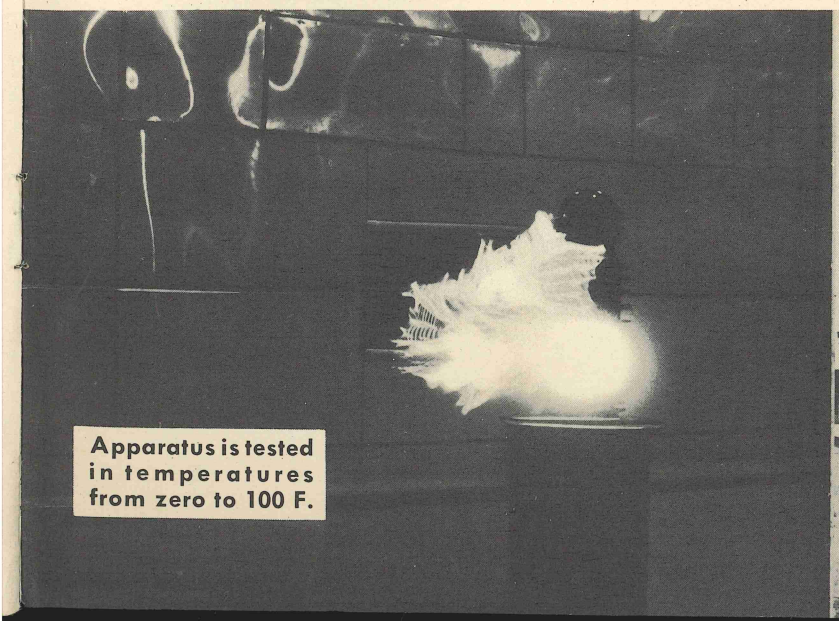
Julius H. Hagenguth, in charge of G-E high-voltage research since 1945, is pictured with a measuring device.

The Damage Is Great

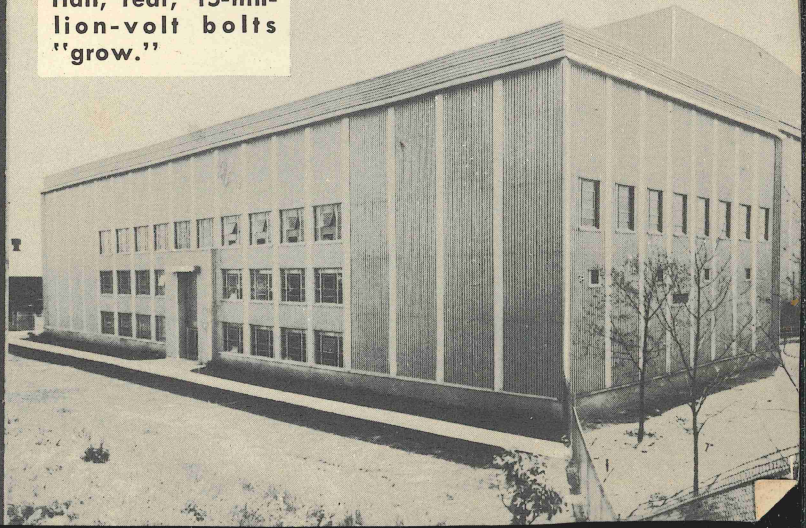
Reports of the U. S. Census Bureau show that nearly 2000 Americans are killed or injured each year by lightning. Thousands of acres of forest are destroyed by the fires it starts.

As noted before, lightning can and will strike the same place twice, or many times. The very fact that lightning has struck once is a warning that conditions are right for proper grounding and it may happen again.

Explained simply, lightning occurs when negative electrical charges which mass in the lower portion of a thundercloud, have become concentrated enough and strong enough to jump the air gap to earth to join with positive



Apparatus is tested in temperatures from zero to 100 F.



In High Voltage Hall, rear, 15-million-volt bolts "grow."

For outdoor tests a giant high-voltage generator moves on a flatcar through a 50-foot high doorway.

electrical charges which have been attracted to the surface by the negative charges.

A Strange Probability

However, the action is not all downward. Electrical streamers rising out of the ground to meet a descending bolt have been photographed. Hence, oddly enough, a person struck by lightning probably is "struck up" from the ground before being "struck down" from the sky.

Contrary to popular belief, not every lightning flash is accompanied by thunder. Thunder, and also the physical destruction of lightning, is the result of the sudden expansion of air created by a fast-moving electrical discharge. But lightning bolts vary in speed; and if the electric current to earth is slow enough, say one- or two-tenths of a second instead of millionths of a second, there is no thunder. It all looks the same to the human eye.

The "weapon of the gods" doesn't play the rogue all the time. In one role lightning is a benefactor. Roughly 100,000,000 tons of nitrogen, an essential agriculture chemical, is deposited by natural lightning over the earth's surface each year. Air, which is about four-fifths nitrogen, is broken down by the passage of a bolt of lightning, and the fixed nitrogen is washed into the soil by rain.

A Natural Mystery

Another of nature's queerest mysteries is "ball lightning." Though many individuals swear they have seen a ball of fire float through an open window, bounce along the ground, or perform similar antics, scientists aren't sure it actually exists. Still, men whose veracity is unquestionable, claim to have seen it. This "ball lightning" is described usually as reddish pink, indefinite in outline, and occurring during thunderstorms. Some other reporters claim no storm was in progress when the phenomenon was seen. Lightning hunters haven't obtained any records of "ball lightning" yet.

Probably one of the oldest, simplest, and at the same time, most useful electrical appliances known to man is the lightning rod. Its principal use is in rural areas, where isolated farm buildings are much more apt to be struck, and when struck, the damage may be much greater because good fire protection is lacking. (Nine-tenths of the annual 2000 American lightning casualties occur in the country or in small towns. The city dweller and his home are protected by tall steel-frame buildings which are themselves lightning rods.)

The duty of the lightning rod and its ground connections is plain. Projecting a few feet above the building it guards, the rod offers to the normally destructive bolt of lightning an unobstructed and easy pathway to the ground. Properly installed lightning rods often save many times their cost in fire prevention alone. Oil and gasoline tanks and ammunition dumps are all well protected by lightning rods.

You're in the Picture

What of lightning and you? Though scientists and engineers in such places as General Electric's High-Voltage Engineering Laboratory have developed protective devices for building and electric equipment, people can't be wired and grounded at will. There are, however, a few precautions which individuals may follow for their own safety.

There are two places in the home that afford absolute protection against any lightning bolt; the refrigerator and the furnace. Of course, you may freeze or roast, but you won't get struck by lightning. For practical purposes, however, just carry on ordinary routine during a thunderstorm, with these exceptions: (1) avoid overhead wires, (2) don't use the telephone unless it's necessary, and (3) stay out of the bathtub. Actually there is very little danger of being killed or injured by lightning in the modern home, but there's no sense in asking for trouble. (Radio antennae, incidentally, should be properly grounded.)

Do not swim during a storm. One of the most dangerous places for a person to be is in or on the water when lightning is flashing nearby. Despite the low target presented by a lake, for instance, water is often struck by lightning. The chances of being hit directly are slim, but the flow of current through water in which you are swimming is very dangerous.

Things to Watch

A golf course is not the best place to be during a lightning storm, though it's no more dangerous than any other open field. It isn't advisable to carry a metal club on your shoulder if you do happen to be caught on the links by a storm.

Also, it's not healthy to stand under a tree while lightning and thunder blast away from above, especially an isolated tree. You might argue that the tree would act as a natural lightning rod, affording a cone of protection. This is not the case. A tree can't carry large volumes of current; the lightning bolt may jump away from it at any point, toward a more desirable conductor. Thus, a person standing under a tree that's struck by lightning may be hit by a side-flash. Also, flying branches and splinters are dangerous.

One of the best places to be during a thunderstorm is in an automobile, where you are nearly surrounded by a metal body. Also, steel-frame buildings are usually quite safe, because the framework carries the charges off to the ground harmlessly.

Dr. McEachron, the noted General Electric lightning expert, offers a bit of philosophy about lightning. He says:

"If you heard the thunder, the lightning did not strike you. If you saw the lightning, it missed you; and if it did strike you, you would not have known it."

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